Countermeasures in Forest Ecosystems: a Preliminary Classification in Term of Dose Reduction and Ecological Quality

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INTRODUCTION

Overall in Europe, forests account for about 28% of the total land area.[1,2] It is interesting to note that in contrast to other parts of the world, recent trends in land use in Europe have shown a general decline in arable/cropland and an increase in forests.

In the aftermath of the accident at Chernobyl, it was difficult to define the contribution to the dose to man from forests and to adopt well-justified countermeasures, because there was very little information relating to the impact to man of radioactive fallout on forests. After the fallout from atmospheric nuclear weapons testing, in the 1960's, considerable attention was paid to the effect of fallout on agricultural products, drinking water, etc. but only the lichen-caribou-man and lichen-reindeer-man food chain was studied for natural and semi-natural environments.[3,4] The few observations in semi-natural environments in the 1960's and the studies carried out after the Kystym accident (in which mainly Sr-90 was released) showed that in these environments, radionuclides remain available for a longer time than in agricultural systems.[5]

In the wake of the Chernobyl accident, it became apparent that forest ecosystems are very important sources of dose to man which demand careful management. Nine years after the Chernobyl event, the ^{137}Cs concentrations in plants grown in forests and in meadows had not declined significantly [6] Meat and milk from animals grazing on clearings as well as mushrooms, wild berries and game, contribute a significant dose to man.[7] Restrictions in the use of food products coming from semi-natural ecosystems are still necessary in some heavily contaminated areas of Belarus.[7] At present, the intake of radiocaesium and radiostrontium through food from semi-natural systems is, in some areas, the greatest contribution to the dose to man. Additionally, external doses may be received by forestry workers and groups of population using timber for furniture or building material. Wood industries, like pulp mills, consuming large amounts of wood, concentrate radionuclides in their waste products. In highly contaminated areas these wastes can be a source of external dose to workers in wood industries. Furthermore, in the heavily contaminated areas of CIS countries, forests are a potential reservoir of secondary contamination and forest fires represent a resuspension risk. In the long-term, the contribution to the dose to man from forests may be, for some groups of population, more important than that from agricultural and urban areas.[7]

Countermeasures aim to minimise the radiological impact to man of nuclear contamination of an environment. Their effectiveness is generally expressed in terms of dose reduction. The design of a post-nuclear accident management strategy involves appraisal of the benefits of dose reduction versus the cost of implementation. The cost of implementation is generally calculated as a function of manpower, equipment, consumables and in some cases waste disposal. Experience since the Chernobyl accident has demonstrated that additional factors relating to practicality and side effects must be considered during the evaluation of countermeasure options.

The aim of this paper is to evaluate the state of knowledge in Europe with respect to countermeasures in forest ecosystems and to suggest a preliminary classification in terms of dose reduction and ecological quality.

DISCUSSION

A Preliminary Classification of Countermeasures in Forest

In the last 12 years, considerable research has been carried out in Europe aimed at devising countermeasures for reducing the radiological impact of land contaminated by the Chernobyl fallout. Table 1 presents a summary of the countermeasures evaluated so far which have potential for use in forests. Little research has been targeted specifically at forest ecosystems. The majority of the countermeasure research is related to agriculture and application to forests has by and large not been tested. The research also focused mainly on the effectiveness of the countermeasure whereas practicality of application and potential secondary impacts of the countermeasures were seldom reported. Because of the lack of direct forest research in many cases it was necessary to extrapolate conclusions based on agricultural systems to the forest ecosystem.

A first classification of the countermeasures reported in Table 1 has been carried out considering their applicability, the timing of countermeasure application, the time period over which the countermeasures is effective and their impact on ecological quality.

Table 1. Forest Countermeasures

Counter-measure Type	Action taken/ Application	Practicality/Suitability	Secondary Ecological Effects
Soil Based chemical/ additive	• Clay minerals • Potassium • Liming	• Most effective on organic soils • Application and adequate mixing in forest soils is impractical due to presence of roots and understory vegetation	• Change in floral composition recorded on upland organic pastures treated with bentonite and lime. • May alter availability of fungi and forest fruits • K may enhance understorey biomass but the effect will be short lived • K may limit bioavailability of micronutrients • Excessive lime treatment may reduce the fine root biomass of conifers • Liming can reduce the bioavailability of essential nutrients especially P
Soil Based physical	• Ploughing • Soil surface removal	• Impractical due to physical heterogeneity of the forest floor and poor equipment access.	• Damage to roots and geophytic plants • Destruction of understorey vegetation • Ploughing displaces contamination to deeper in the soil profile • Potential contamination of ground water • Erosion risk • Loss or dilution of nutrient pool in surface soil layers • Organic soil removal generates 5-100t/ha of contaminated waste • Each additional 1cm removal of mineral soil generates 100-150t/ha of contaminated waste • Loss of forest grazing • Alternative fodder required • Loss of forest fruits and fungi • Loss of game/hunting • Alternative foods required • Reduction of amenity value
	• Litter removal	• Over a small area (urban park) litter removal may be done manually • To be effective, timing is critical	• Damage to understorey vegetation • Minor loss of nutrients • Generation of contaminated waste

Table 1. Forest Countermeasures (continued)

Counter-measure Type	Action taken/ Application	Practicality/Suitability	Secondary Ecological Effects
Forest Management	• Restrict human access to forest	• Difficult to enforce • Education required • Forest maintenance and fire prevention must be continued	• Loss of forest grazing • Loss of forest fruits and fungi • Loss of hunting • Alternative foods required • Reduced control over game population • Loss of amenity value • Loss of fire-wood • Negative psychological impact
	• Restrict access by grazing animals	• Difficult to enforce • Education required	• No ecological effects • Alternative fodder required • Negative psychological impact
	• Restrict consumption of forest foods	• Difficult to enforce • Education required	• Loss of forest fruits and fungi • Loss of hunting • Alternative foods required • Reduced control over game population • Loss of amenity value • Negative psychological impact
	• Change game hunting season	• Difficult to enforce • Education required	• Reduced game weights • Game may be more difficult to locate • Change in traditional practices
	• Delay forest felling	• Forest maintenance and fire prevention must be continued	• Enhanced risk of timber loss through disease and wind fall • Possible loss of timber quality • Loss of employment • Prolonged amenity value

Counter-measure Type	Action taken/ Application	Practicality/Suitability	Secondary Ecological Effects
	• Change to nursery production	• Staff retraining required • Equipment requirement • Market required	• Disposal of clearfelled trees • Change of landscape • Change of forest ecology • Loss of understorey vegetation • Loss of forest fruits and fungi • Loss of hunting • Alternative foods required • Loss of amenity value • High fertilizer demand • Altered hydrology • Soil erosion risk • Possible contamination of water bodies • Migration of game to alternative habitats • Change in employment pattern • Loss of timber processing industry • Spread of contamination via saplings
Tree Based Chemical	• Defoliation and removal of leaves/ needles	• Timing is critical • More applicable to deciduous trees	• Leaf loss will damage trees severely • Defoliant may have toxic effect on flora and fauna • Possible contamination of water bodies • Access by humans and domestic animals may be restricted • Hunting and wild food collection may be suspended • Alternative foods and fodder required • Minor loss of nutrients • Generation of contaminated waste • Alteration of landscape • Negative psychological impact

Applicability

The application of countermeasures can be optimised on the basis of knowledge about the effects of soil type on transfer of radionuclides to forest biomass. Depending on soil characteristics particular forests may require restrictions applicable to a more (or less) contaminated zone. For example, forests on hydromorfic soils (with a well developed holorganic layer) have a high transfer of contamination to wood so require restrictions applicable to a more contaminated zone (one class more severe). Less strict limitations (one contamination class) are required on soils with heavy texture (clay and loamy soils). Soil type may also be used to prioritise the application of countermeasures.

Timing of Application

The evaluation of the benefit in terms of dose reduction by some countermeasures depends on time elapsed from the deposition and on the characteristics of the forests. Litter removal for example would be more effective for deciduous trees if contamination occurs just before autumn. If the contamination occurs at other periods for deciduous trees and for coniferous trees in general this method could be effective from six months to one year after the accident. In the case of the Chernobyl accident, litter removal carried out in autumn 1986 could have removed between 10 to 20% of the total radiocaesium deposit.[8] Similarly, tree defoliation is only effective while the canopy retains the contamination. Data from Chernobyl show that 80-90% of total forest contamination could be removed by defoliation within the first 6 months of the accident.[8] In the analysis of the cost computation of this remediation action it is necessary to consider the cost of the transport and the treatment of a large volume of radioactive waste. The relatively slow migration of radionuclides in the forest soil[4] means that timing is not so critical for soil based or forest management countermeasures.

Duration of Effect

Information on the persistence of radionuclides in the forest compartments and knowledge of the dynamics of radionuclides in these ecosystems are required to determine the duration of effect of the different countermeasures. The duration of effect is a major component of the calculation of averted dose. Data collected in the wake of the Chernobyl accident have shown that tree wood will become increasingly contaminated and the ^{137}Cs concentration will reach a maximum between the years 1998 and 2010.[9] Data on mushrooms show that for some species there is no significant decrease with time.[8] These data indicate, therefore, that remediation measures taken soon after contamination will have a long term dose saving effect.

Defoliation and litter removal have long term benefits in that they reduce the contamination source in the forest - but the waste produced by these actions present long-term disposal problems.

Restriction of access to forests and use of forest products results in an instantaneous dose reduction but this action must be sustained over many years to be continually effective. These measures require the population to change traditional practices which involves the loss, for extended periods, of foodstuffs traditionally collected in the forest. The economic effect may be significant and the cultural change can cause a strong negative psychological impact on the population.

Ecological Effects

Secondary impacts on the forest as a result of countermeasure application are important considerations in countermeasure evaluation because very often the direct economic costs associated with the action (for example, loss of timber value) are less important than the impact on other forest functions. Forests have many functions in the environment (e.g., a production system for wood for industry and fuel, a habitat, a grazing place for domestic animals, a source of food, a territory for game, a recreation ground for man, a feature of the landscape). The forest gives stability to soil, intercepts precipitation and forms an attractive barrier to sound, unpleasant views and airborne contaminants. The more functions, either economic, social or environmental that a forest has, the greater its value and the more precious its ecology.

A classification of forest countermeasures in terms of their impact on the forest ecology must consider both the severity of the secondary effects as well as the range of functions which will be put at risk by this secondary effect. Table 1 indicates the potential secondary impacts of the listed countermeasures. It is clear that some have more potential effects than others.

The majority of research effort has targeted soil-based countermeasures which are most effective in agricultural situations. The important role of soil in the bio- and geo-sphere means that there is potentially a very wide range of secondary effects associated with any interference in soil. The radiological literature which propose soil based countermeasures do not do justice to the important role of soil in the environment.

Table 1 lists both physical and chemical soil amendments as countermeasures and indicates that chemical applications to soil are less ecologically damaging than the physical. Any of the impacts listed will be magnified if a large forested area are to be treated. Changes to the forest soil will affect the availability of forest fruits and the use of the forest for grazing. In small forested areas such as in an urban parkland, these measures may be justified on the basis of the large social benefit to be derived from the preservation of a parkland. In this case, any secondary effects of the countermeasure which risked the health of the forest would defeat the purpose of remediation.

Chemical defoliation is a frequently suggested action but the loss of all leaves is a severe shock to the physiology of a tree, especially to coniferous trees. In addition to this effect, there are significant potential ecological hazards associated with the defoliant. The defoliant is likely to affect all of the forest flora with knock-on effects in the forest fauna. There is also a risk that the defoliant could spread to water bodies. As with the soil based countermeasures the potential secondary effects associated with defoliation may be acceptable for small area treatments where understorey vegetation has not got a food role.

CONCLUSION

With forest management measures there are few direct losses of ecological quality. However, the restriction of forest use by the public reduces the value of the forest to the local community which in turn can negatively impact the public perception of the wider environment and of their quality of life. This indicates again the important role of public education programs in such forest management based countermeasures. Listed under forest management is the option to change forestry production to one of nursery production. This management option preserves commercial activity but it is dependent on the availability of markets and it would require a shift in the labour patterns. This action also has the most severe ecological consequences because it involves the loss of the forest itself and every function which it performed in the community and the environment.

REFERENCES

1. United Nations Environmental Programme Environmental Data Report, 1991. Blackwell, Oxford.

2. The agricultural situation in the Community, 1991 Report. Commission of the European Communities, 1992, Luxembourg.

3. Bird, P.M.; 1968, Studies of Fallout ^{137}Cs in the Canadian North; Archives of Environmental Health; 1968, 17, 631 638.

4. Bird, P.M.; Radionuclides in Foods; The Canadian Medical Association Journal; 1966, 94, 590-597.

5. Alexakhin, R.M., Ginsburg, L.R., Mednik, I.G, Prokhorov V.M.; 1994, Model of 90Sr Cycling in a Forest Biogeocenosis; The Science of the Total Environment; 1994, 157, 83-91.

6. Belli, M., Tikhomirov F.A, Kliashtorin, A., Shchlegov A., Rafferty, B., Shaw, G., Wirth, E., Kammerer, L., Ruehm, W., Steiner, M., Delvaux, B., Maes, E., Kruyts, N., Bunzl, K., Dvornik, A.M. and Kuchma, N., 1996, Dynamics of radionuclides in forest environments, Proceedings of the First International Conference on the Radiological Consequences of the Chernobyl Accident. European Commission and the Belarus, Russian and Ukrainian Ministries on Chernobyl Affairs, Emergency Situations and Health, 69-80, EUR 16544 EN.

7. Strand, P., Balonov, M., Skuterud, L., Hove, K., Howard, B., Prister, B.S., Travnikova and Ratnikov, A., 1996, Exposure from consumption of agricultural and semi-natural products, Proceedings of the First International Conference on the Radiological Consequences of the Chernobyl Accident. European Commission and the Belarus, Russian and Ukrainian Ministries on Chernobyl Affairs, Emergency Situations and Health, 261-269, EUR 16544 EN.

8. Belli, M. & Tikhomirov F.A. editors; 1996, Behaviour of radionuclides in natural and semi-natural environments; Final Report of ECP-5 Project (1991-1996), EUR 16531.

9. Tikhomirov F.A., Shchlegov A. and Sidorov, V.P.; 1993, Forest and Forestry: radiation protection measures with special reference to the Chernobyl accident zone. Sci. Total Environ., 1993, 137 289- 305.

Phytoextraction and Phytostabilization of Radionuclides in Contaminated Soils

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INTRODUCTION

Remediation of soils contaminated with radionuclides has historically been removal and replacement of the soil. New approaches to remediate the risk of soil radionuclides by phytoremediation (phytoextraction or phytostabilization) are being developed. In phytoextraction, plant species which accumulate unusually high concentrations (have very high bioconcentration factors) compared to crop plants are being grown as a "hay" crop. The hay is grown using management practices to maximize yield and accumulation of the contaminant, dried in the field, baled, and the biomass burned or pyrolyzed to produce a concentrated ash which is a significant part of the total soil contaminant in a small mass. This reduces the cost of appropriate disposal of the contaminants, and retains soil fertility. During the remediation period, cropping limits wind or water erosion of the contaminated soil, and evapotranspiration reduces potential for leaching.

DISCUSSION

Phytostabilization uses application of chemicals or soil amendments which reduce the bioavailability of the contaminant in soil. Plants may play a direct role by oxidation of xenobiotics, or by accumulating an element needed to inactivate a contaminant (such as accumulating phosphate which improves the rate of formation of chloropyromorphite, a crystalline Pb solid which has very low bioavailability). Application of adsorbents such as hydrous Fe and Mn oxides can increase adsorption or precipitation of a contaminant, or favor occlusion within the more crystalline solids formed over time. If bioavailability is persistently reduced such that environmental risk is reduced to required levels of protection, phytostabilization can be a practical remediation. Demonstration of the persistence of the reduction in bioavailability is a necessary to win acceptance of phytostabilization.

Technologies are under development for phytoremediation/phytoextraction of the elements Zn, Cd, Ni, Co, and Se using hyperaccumulator plants, and for Hg and Se using phytovolatilization. Soil and crop management practices are being optimized to maximize annual removals. Evidence has been reported that some radionuclides (Cs, Sr, Co) can be effectively phytoextracted, and more radionuclides are being studied. Addition of chelating agents can increase uptake of some metals or radionuclides, but leaching would need to be controlled if this approach were applied in the field.

Application of phytoextraction to specific radionuclides using specific plants. We have completed a Critical Review of the literature on Phytoremediation of Soil Radionuclides to identify both promising plant species for specific radionuclides, and appropriate methods for evaluation of phytoextraction, and a Report is being prepared.

Response Criteria

Response Actions are limited reactions to releases of hazardous substances into the environment to minimize hazard or dispersal. Phytostabilization could be an Emergency Response wherein cover crops which have reduced uptake of radionuclides of concern are grown on the site. An effective vegetative cover can be achieved on nearly any site if soil analysis is conducted to identify deficient nutrients or toxic elements, and existing pH and adsorption ability of the soil. Inexpensive locally available byproducts may provide needed changes in soil nutrients and toxic element phytoavailability so that desired plants can be grown; plant species which exclude radionuclides from food-chain plant tissues could be sown and maintained using conventional agricultural practices.

CONCLUSION

Phytoextraction as a Response Technology?

Thus the Agency has begun to gather information about phytoremediation and its possible application as a cleanup technology. Bioremediation and Phytoremediation have some similarities in their application to contaminated soils, and present similar issues to On Scene Coordinators considering use following a release event. We believe that research and demonstration of radionuclide phytoextraction will show the ability of this technology to achieve practical remediation of soil radionuclides, and provide the information needed for public decisions on use of phytoextraction of contaminated sites.